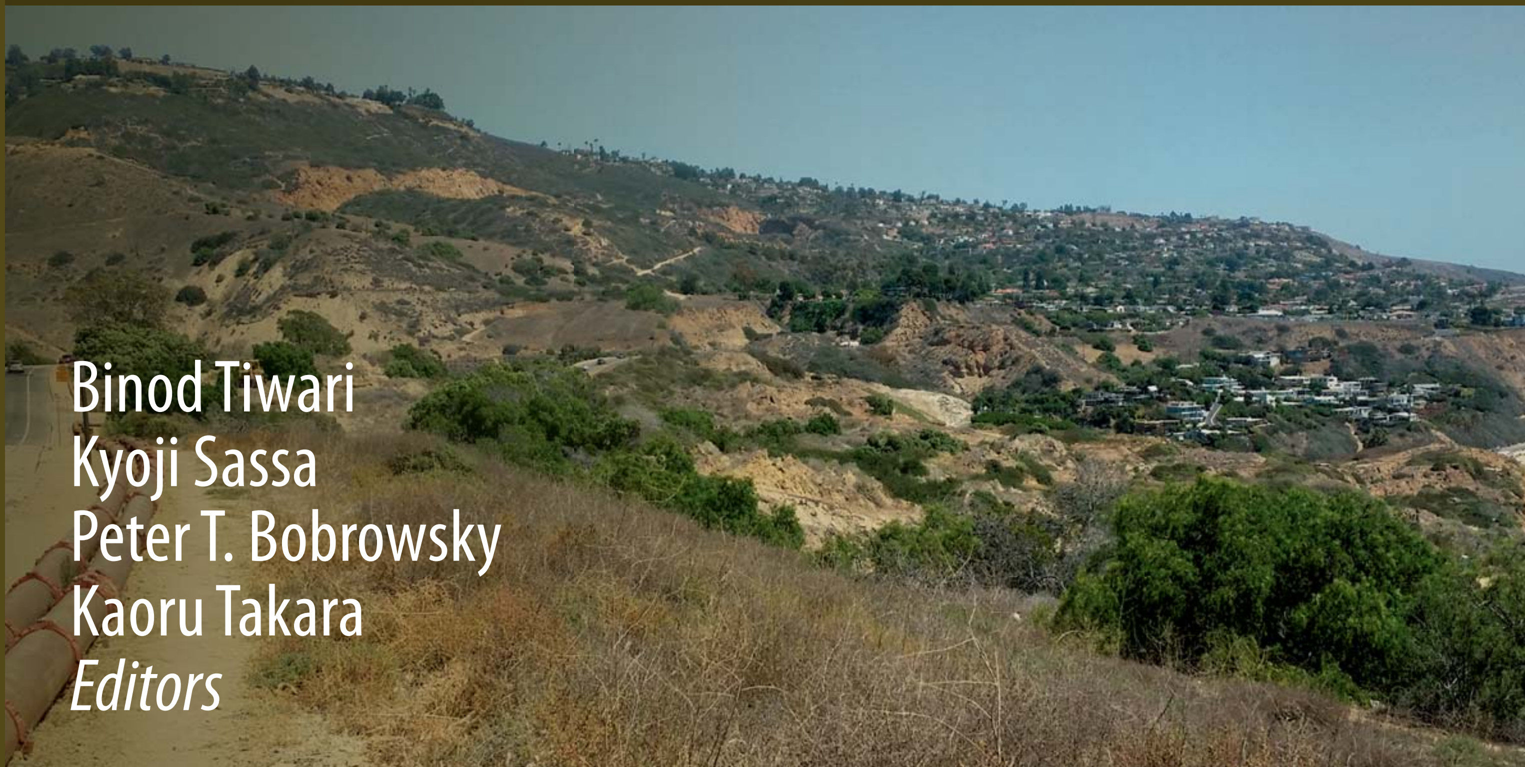
ICL Contribution to Landslide Disaster Risk Reduction



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Kyoji Sassa
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Editors

Understanding and Reducing Landslide Disaster Risk

Volume 4 Testing, Modeling and Risk Assessment

ICL

Springer

ICL Contribution to Landslide Disaster Risk Reduction

Series Editor

Kyoji Sassa, The International Consortium on Landslides, ICL, Kyoto, Japan

The ICL Contribution to Landslide Disaster Risk Reduction book-series publishes integrated research on all aspects of landslides. The volumes present summaries on the progress of landslide sciences, disaster mitigation and risk preparation. The contributions include landslide dynamics, mechanisms and processes; volcanic, urban, marine and reservoir landslides; related tsunamis and seiches; hazard assessment and mapping; modeling, monitoring, GIS techniques; remedial or preventive measures; early warning and evacuation and a global landslide database.

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Peter T. Bobrowsky • Kaoru Takara
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ICL and Springer created a new book series “ICL Contribution to Landslide Disaster Risk Reduction” in 2019 which is registered as ISSN 2662-1894 (print version) and ISSN 2662-1908 (electronic version). The first books in this series are six volume of books “Understanding and Reducing Landslide Disaster Risk” containing the recent progress of landslide science and technologies from 2017 to 2020.

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Foreword by Mami Mizutori

More landslides can be expected as climate change exacerbates rainfall intensity. The long-term trend of the last 40 years has seen the number of major recorded extreme weather events almost double, notably floods, storms, landslides, and wildfires.

Landslides are a serious geological hazard. Among the host of natural triggers are intense rainfall, flooding, earthquakes or volcanic eruption, and coastal erosion caused by storms that are all too often tied to the El Niño phenomenon. Human triggers including deforestation, irrigation or pipe leakage, and mine tailings, or stream and ocean current alteration can also spark landslides. Landslides can also generate tsunamis, as Indonesia experienced in 2018.

Globally, landslides cause significant economic loss and many deaths and injuries each year. Therefore, it is important to understand the science of landslides: why they occur, what factors trigger them, the geology associated with them, and where they are likely to happen.

Landslides with high death tolls are often a result of failures in risk governance, poverty reduction, environmental protection, land use and the implementation of building codes. Understanding the interrelationships between earth surface processes, ecological systems, and human activity is the key to reducing landslide risk.

The Sendai Framework for Disaster Risk Reduction, the global plan to reduce disaster losses adopted in 2015, emphasizes the importance of tackling these risk drivers through improved governance and a better understanding of disaster risk.

One important vehicle for doing that is the Sendai Landslide Partnerships 2015–2025 for global promotion of understanding and reduction of landslide risk facilitated by the International Consortium on Landslides (ICL) and signed by the leaders of 22 global stakeholders, including the UN Office for Disaster Risk Reduction (UNDRR), during the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan.

The Sendai Landslide Partnerships—featured on the Sendai Framework Voluntary Commitments online platform—helps to provide practical solutions and tools, education, and capacity building, to reduce landslide risks.

The work done by the Sendai Partnerships can be of value to many stakeholders including civil protection, planning, development and transportation authorities, utility managers, agricultural and forest agencies, and the scientific community.

UNDRR fully supports the work of the Sendai Landslide Partnerships and ICL and looks forward to an action-oriented outcome from the 5th World Landslide Forum to be held in November 2020 in Kyoto, Japan. Successful efforts to reduce disaster losses are a major contribution to achieving the overall 2030 Agenda for Sustainable Development.

Mami Mizutori
United Nations Special Representative of the
Secretary-General for Disaster Risk Reduction

Foreword by the Assistant Director-General for the Natural Sciences Sector of UNESCO for the Book of the 5th *World Landslide Forum*

As the world slowly recovers from the COVID-19 global pandemic, and looking back at the way this crisis developed, it becomes evident that as a global community we were not prepared for an event of this scale. Although not commonly perceived as such, biological hazards such as epidemics are included in the Sendai Framework for Disaster Risk Reduction 2015–2030. In that sense, the preparedness approach for a pandemic is very similar to that of a geophysical natural hazard such as landslides.

Although natural hazards are naturally occurring phenomena, the likelihood of their occurrence and of associated disasters is rising. Climate change, urban pressure, under-development and poverty and lack of preparedness are increasingly transforming these natural hazards into life-threatening disasters with severe economic impacts. Therefore, Disaster Risk Reduction (DRR) is gaining momentum on the agenda of the UN system of Organizations including UNESCO. While the Sendai Framework for Disaster Risk Reduction 2015–2030 is the roadmap for DRR, other global agendas including the Sustainable Development Goals, the Paris Climate Agreement and the New Urban Agenda have targets which cannot be attained without DRR.

In shaping its contribution to those global agendas, UNESCO is fully committed in supporting its Member States in risk management, between its different mandates and disciplines and with relevant partners. The International Consortium on Landslides (ICL) is UNESCO's key partner in the field of landslide science. The Organization's support to the Consortium is unwavering. Since ICL was established in 2002, the two organizations have a long history of cooperation and partnership and UNESCO has been associated with almost all of ICL activities. I am very glad that ICL and UNESCO are mutually benefitting from their collaboration.

The 5th World Landslide Forum (WLF5) is expected to represent a milestone in the history of landslide science particularly for scientists and practitioners. One of the major outcomes of WLF5 will be the Kyoto 2020 Commitment for global promotion of understanding and reducing landslide disaster risk (KLC2020). This commitment is expected to strengthen and expand the activities of the Sendai Landslide Partnership 2015–2025. With UNESCO already engaged as a partner, the adoption of this international commitment will raise global awareness on landslide risk and mobilize wider partnerships that draw together stakeholders from all levels of society, across different regions, sectors and disciplines.

It is my great pleasure to congratulate the organizers for holding this event and assure you that UNESCO is fully committed in contributing to its success. As part of that contribution, our Organization is proud to host a session on landslides and hazard assessment at UNESCO-designated sites such as natural World Heritage sites, biosphere reserves and UNESCO Global Geoparks. This session aims to assess landslide impacts on our shared cultural and natural heritage, providing the best opportunity to generate public awareness and capacity development for landslide disaster reduction.

I am confident that WLF5 will contribute to further advance the knowledge of both scientists and practitioners regarding landslide disaster risk reduction. This book paves the way for the science, knowledge and know-how which will feature in the deliberations of the Forum. UNESCO commends all of the contributors to this publication. I look forward to an enhanced collaboration between UNESCO and ICL in future activities and undertakings.

Shamila Nair-Bedouelle
Assistant Director-General for Natural Sciences
UNESCO

Preface I

Understanding and Reducing Landslide Disaster Risk

Book Series: ICL Contribution to Landslide Disaster Risk

The International Consortium on Landslides (ICL) was established in pursuance of the 2002 Kyoto Declaration "Establishment of an International Consortium on Landslides," with its Statutes adopted in January 2002. The Statutes define the General Assembly of ICL as follows: in order to report and disseminate the activities and achievements of the Consortium, a General Assembly shall be convened every 3 years by inviting Members of the International Consortium on Landslides, individual members within those organizations, and all levels of cooperating organizations and individual researchers, engineers, and administrators. The General Assembly developed gradually prior to, during and after its first meeting in 2005. In the light of the 2006 Tokyo Action Plan, the Assembly was further facilitated at, and following the First World Landslide Forum held in November 2008. On the occasion of each of its triennial forums, ICL publishes the latest progress of landslide science and technology for the benefit of the whole landslide community including scientists, engineers, and practitioners in an understandable form. Full color photos of landslides and full color maps are readily appreciated by those from different disciplines. We have published full color books on landslides at each forum. In 2019, ICL created a new book series "ICL Contribution to Landslide Disaster Risk Reduction" ISSN 2662-1894 (print version) and ISSN 2662-1908 (electronic version). Six volumes of full color books *Understanding and Reducing Landslide Disaster Risk* will be published in 2020 as the first group of books of this series.

The Letter of Intent 2005 and the First General Assembly 2005

The United Nations World Conference on Disaster Reduction (WCDR) was held in Kobe, Japan, 18–22 January 2005. At this Conference, ICL organized session 3.8 "New international Initiatives for Research and Risk Mitigation of Floods (IFI) and Landslides (IPL)" on 19 January 2005 and adopted a "Letter of Intent" aimed at providing a platform for a holistic approach in research and learning on 'Integrated Earth System Risk Analysis and Sustainable Disaster Management'. This Letter was agreed upon and signed, during the first semester of 2005, by heads of seven global stakeholders including the United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Meteorological Organization (WMO), the Food and Agriculture Organization of the United Nations (FAO), the United Nations International Strategy for Disaster Risk Reduction (UNISDR-currently UNDRR), the United Nations University (UNU), the International Council for Science (ICSU-Currently ISC), and the World Federation of Engineering Organizations (WFEO).

The first General Assembly of ICL was held at the Keck Center of the National Academy of Sciences in Washington D.C., USA, on 12–14 October 2005. It was organized after the aforementioned 2005 World Conference on Disaster Reduction (WCDR). ICL published the first full color book reporting on Consortium activities for the initial 3 years, 2002–2005 titled "Landslides-Risk analysis and sustainable disaster management". In the preface of this book, the Letter of Intent for Integrated Earth System Risk Analysis and Sustainable Disaster Management was introduced. Results of the initial projects of the International Programme on Landslides (IPL) including IPL C101-1 Landslide investigation in Machu Picchu World Heritage, Cusco, Peru and previous agreements and MoU between UNESCO, ICL and the Disaster Prevention Research Institute of Kyoto University including UNESCO/KU/ICL UNITWIN Cooperation programme were published as well in this book.

The 2006 Tokyo Action Plan and the First World Landslide Forum 2008

Based on the Letter of Intent, the 2006 Tokyo Round-Table Discussion—"Strengthening Research and Learning on Earth System Risk Analysis and Sustainable Disaster Management within UN-ISDR as Regards Landslides"—towards a dynamic global network of the International Programme on Landslides (IPL) was held at the United Nations University, Tokyo, on 18–20 January 2006. The 2006 Tokyo Action Plan—Strengthening research and learning on landslides and related earth system disasters for global risk preparedness—was adopted. The ICL exchanged Memoranda of Understanding (MoUs) concerning strengthening cooperation in research and learning on earth system risk analysis and sustainable disaster management within the framework of the United Nations International Strategy for Disaster Reduction regarding the implementation of the 2006 Tokyo action plan on landslides with UNESCO, WMO, FAO, UNISDR (UNDRR), UNU, ICSU (ISC) and WFEO, respectively in 2006. A set of these MoUs established the International Programme on Landslides (IPL) as a programme of the ICL, the Global Promotion Committee of IPL to manage the IPL, and the triennial World Landslide Forum (WLF), as well as the concept of the World Centres of Excellence on Landslide Risk Reduction (WCoE).

The First World Landslide Forum (WLF1) was held at the Headquarters of the United Nations University, Tokyo, Japan, on 18–21 November 2008. 430 persons from 49 countries/regions/UN entities were in attendance. Both Hans van Ginkel, Under Secretary-General of the United Nations/Rector of UNU who served as chairperson of the Independent Panel of Experts to endorse WCoEs, and Salvano Briceno, Director of UNISDR who served as chairperson of the Global Promotion Committee of IPL, participated in this Forum. The success of WLF1 paved the way to the successful second and third World Landslide Forum held in Italy and China respectively.

The Second World Landslide Forum 2011 and the Third World Landslide Forum 2014

The Second World Landslide Forum (WLF2)—Putting Science into Practice—was held at the Headquarters of the Food and Agriculture Organization of the United Nations (FAO) on 3–9 October 2011. It was jointly organized by the IPL Global Promotion Committee (ICL, UNESCO, WMO, FAO, UNDRR, UNU, ISC, WFEO) and two ICL members from Italy: the Italian Institute for Environmental Protection and Research (ISPRA) and the Earth Science Department of the University of Florence with support from the Government of Italy and many Italian landslide-related organizations. It attracted 864 participants from 63 countries.

The Third World Landslide Forum (WLF3) was held at the China National Convention Center, Beijing, China, on 2–6 June 2014. A high-level panel discussion on an initiative to create a safer geoenvironment towards the UN Third World Conference on Disaster Risk Reduction (WCDRR) in 2015 and forward was moderated by Hans van Ginkel, Chair of Independent Panel of Experts for World Centers of Excellence (WCoE). In a special address to this high-level panel discussion, Irina Bokova, Director-General of UNESCO, underlined that countries should be united to work against natural disasters and expressed commitment that UNESCO would like to further deepen cooperation with ICL. Ms. Bokova awarded certificates to 15 World Centres of Excellence.

The Sendai Landslide Partnerships 2015 and the Fourth World Landslide Forum 2017

The UN Third World Conference on Disaster Risk Reduction (WCDRR) was held in Sendai, Japan, on 14–18 March 2015. ICL organized the Working Session "Underlying Risk Factors" together with UNESCO, the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and other competent organizations. The session adopted ISDR-ICL Sendai Partnerships 2015–2025 (later changed to Sendai Landslide Partnerships) for global promotion of understanding and reducing landslide disaster risk as a Voluntary Commitment to the World Conference on Disaster Risk Reduction, Sendai, Japan, 2015 (later changed to Sendai Framework for Disaster Risk Reduction). After the session on 16 March 2015, the Partnerships was signed by Margareta Wahlström, Special Representative of the UN Secretary-General for Disaster Risk Reduction, Chief of UNISDR (UNDDR), and other representatives from 15 intergovernmental, international, and national organizations. Following the Sendai Landslide Partnerships, the Fourth World Landslide Forum was held in Ljubljana, Slovenia from 29 May to 2 June in 2017. On that occasion, five volumes of full color books were published to disseminate the advances of landslide science and technology. The high-level panel discussion on 30 May and the follow-up round table discussion on 31 May adopted the 2017 Ljubljana Declaration on Landslide Risk Reduction. The Declaration approved the outline of the concept of "Kyoto 2020 Commitment for global promotion of understanding and reducing landslide disaster risk" to be adopted at the Fifth World Landslide Forum in Japan, 2020.

The Fifth World Landslide Forum 2020 and the Kyoto Landslide Commitment 2020

The Fifth World Landslide Forum was planned to be organized on 2–6 November 2020 at the National Kyoto International Conference Center (KICC) and the preparations for this event were successfully ongoing until the COVID-19 pandemic occurred over the world in early 2020. The ICL decided to postpone the actual Forum to 2–6 November 2021 at KICC in Kyoto, Japan. Nevertheless, the publication of six volumes of full color books *Understanding and Reducing Landslide Disaster Risk* including reports on the advances in landslide science and technology from 2017 to 2020 is on schedule. We expect that this book will be useful to the global landslide community.

The Kyoto Landslide Commitment 2020 will be established during the 2020 ICL-IPL Online Conference on 2–6 November 2020 on schedule. Joint signatories of Kyoto Landslide Commitment 2020 are expected to attend a dedicated session of the aforementioned Online Conference, scheduled on 5 November 2020 which will also include and feature the Declaration of the launching of KLC2020. Landslides: Journal of the International Consortium on Landslides is the common platform for KLC2020. All partners may contribute and publish news and reports of their activities such as research, investigation, disaster reduction administration in the category of News/Kyoto Commitment. Online access or/and hard copy of the Journal will be sent to KLC2020 partners to apprise them of the updated information from other partners. As of 21 May 2020, 63 United Nations, International and national organizations have already signed the KLC2020.

Call for Partners of KLC2020

Those who are willing to join KLC2020 and share their achievements related to understanding and reducing landslide disaster risk in their intrinsic missions with other partners are invited to inform the ICL Secretariat, the host of KLC2020 secretariat (secretariat@iclhq.org). The ICL secretariat will send the invitation to the aforementioned meeting of the joint signatories and the declaration of the launching of the KLC2020 on 5 November 2020.

Eligible Organizations to be Partners of the KLC2020

1. ICL member organizations (full members, associate members and supporters)
2. ICL supporting organization from UN, international or national organizations and programmes
3. Government ministries and offices in countries having more than 2 ICL on-going members
4. International associations /societies that contribute to the organization of WLF5 in 2021 and WLF6 in 2023
5. Other organizations having some aspects of activities related to understanding and reducing landslide disaster risk as their intrinsic missions.

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Secretary-General of ICL
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Peter T. Bobrowsky
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Executive Director of ICL
Kyoto, Japan

Appendix: World Landslide Forum Books

WLF	Place/participants	Title	Editors	Publisher/pages
WLF0 (1st General Assembly) 2005	Washington D.C., USA 59 from 17 countries/UNs	Landslides-Risk Analysis and Sustainable Disaster Management	Kyoji Sassa, Hiroshi Fukuoka, Fawu Wang, Goghui Wang	Springer/377 pages ISBN: 978-3-540-2864-6
WLF1 2008	Tokyo, Japan 430 from 49 countries/regions/UNs	Landslides-Disaster Risk Reduction	Kyoji Sassa, Paolo Canuti	Springer/649 pages ISBN: 978-3-540-69966-8
WLF2 2011	Rome, Italy 864 from 63 countries	Landslide Science and Practice Vol. 1 Landslide inventory and Sustainability and Hazard Zoning	Claudia Margottini, Paolo Canuti, Kyoji Sassa	Springer/607 pages ISBN: 978-3-642-31324-0
		Vol. 2 Early Warning, Instrumentation and Monitoring		Springer/685 pages ISBN: 978-3-642-31444-5
		Vol. 3 Spatial Analysis and Modelling		Springer/440 pages ISBN: 978-3-642-31309-7
		Vol. 4 Global Environmental Change		Springer/431 pages ISBN: 978-3-642-31336-3
		Vol. 5 Complex Environment		Springer/354 pages ISBN: 978-3-642-31426-1
		Vol. 6 Risk Assessment, Management and Mitigation		Springer/789 pages ISBN: 978-3-642-31318-9
		Vol. 7 Social and Economic Impact and Policies		Springer/333 pages ISBN: 978-3-642-31312-7
WLF3 2014	Beijing, China 531 from 45 countries/regions/UNs	Landslide Science for a Safer Geoenvironment Vol. 1 The International Programme on Landslides (IPL)	Kyoji Sassa, Paolo Canuti, Yueping Yin	Springer/493 pages ISBN: 978-3-319-04998-4
		Vol. 2 Methods of Landslide Studies		Springer/851 pages ISBN: 978-3-319-05049-2
		Vol. 3 Targeted Landslides		Springer/717 pages ISBN: 978-3-319-04995-3
WLF4 2017	Ljubljana, Slovenia 588 from 59 countries/regions/UNs	Advancing Culture of Living with Landslides Vol. 1 ISDR-ICL Sendai Partnerships 2015-2025	Kyoji Sassa, Matjaž Mikoš, Yueping Yin	Springer/585 pages ISBN: 978-319-53500-5

(continued)

WLF	Place/participants	Title	Editors	Publisher/pages
		Vol. 2 Advances in Landslide Science	Matjaž Mikoš, Binod Tiwari, Yueping Yin, Kyoji Sassa	Springer/1197 pages ISBN: 978-319-53497-8
		Vol. 3 Advances in Landslide Technology	Matjaž Mikoš, Željko Arbanas, Yueping Yin, Kyoji Sassa	Springer/621 pages ISBN: 978-3-319-53486-2
		Vol. 4 Diversity of Landslide Forms	Matjaž Mikoš, Nicola Casagli, Yueping Yin, Kyoji Sassa	Springer/707 pages ISBN: 978-3-319-53484-8
		Vol. 5 Landslides in Different Environments	Matjaž Mikoš,Vít Vilímek,Yueping Yin, Kyoji Sassa	Springer/557 pages ISBN: 978-3-319-53482-4
WLF5	2020 (publication) 2021 (Forum)	Understanding and Reducing Landslide Disaster Risk Vol. 1 Sendai Landslide Partnerships and Kyoto Landslide Commitment	Kyoji Sassa, Matjaž Mikoš, Shinji Sassa, Peter T. Bobrowsky, Kaoru Takara, Khang Dang	Springer In Process
		Vol. 2 From mapping to hazard and risk zonation	Fausto Guzzetti, Snježana Mihalić Arbanas, Paola Reichenbach, Kyoji Sassa, Peter T. Bobrowsky, Kaoru Takara	
		Vol. 3 Monitoring and early Warning	Nicola Casagli, Veronica Tofani, Kyoji Sassa, Peter T. Bobrowsky, Kaoru Takara	
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		Vol. 5 Catastrophic landslides and Frontier of Landslide Science	Vit Vilimek, Fawu Wang, Alexander Strom, Kyoji Sassa, Peter T. Bobrowsky, Kaoru Takara	
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Preface II

Landslides, among the most devastating natural disasters in the world, have been, annually, killing thousands of lives, affecting millions of people, and causing billions of dollars of property damage globally. Understanding the causes of specific landslides and their failure mechanisms will help us developing appropriate mitigation measures. Specifically, as landslides directly affect our lifeline infrastructures, applying appropriate engineering judgement while designing sustainable and suitable prevention works using locally available manpower and resources is very important for any strategic landslide management planning. With the advancement of new technology and knowledge, there has been a significant enhancement in the resources available for the analyses of landslides and debris flow disasters, prior to developing their mitigation measures. Dissemination of such information through scientific platforms such as publication, conferences, and global lecture series play an important role in reducing the impact of landslide disasters globally and developing resilient community. More importantly, methods pertinent to in situ and laboratory testing, numerical and experimental as well as physical modeling, and tools available for landslide risk assessment advance very quickly and utilization of globally available resources for landslide testing, modeling, and risk assessment help in promoting global partnership on landslide hazard mitigation. This volume of the book series is intended to compile articles from all over the world, specifically related to recent development on testing, analyzing, modeling, and risk assessment techniques to reduce landslide hazards.

Divided into six parts, this volume includes 5 keynote lectures and 45 peer-reviewed papers in five different research areas pertinent to the theme of this volume, namely, recent development in physical modeling of landslides, recent development in numerical modeling of landslides, recent development in soil and rock testing techniques, application and analysis methods, recent advancements in the methods of slope stability and deformation analyses, and recent development in disaster risk assessment.

The Keynote lectures have been authored by global experts on numerical and physical modeling of landslides, laboratory, and in situ testing of soil and rock, stability and deformation analysis, and landslide risk assessment and cover case studies associated with each topics including but not limited to the seismically induced landslides such as due to the 2015 Gorkha earthquake 1994 Northridge Earthquake, rainfall-induced landslides such as the 2014 Oso Landslide in Washington, and large landslides that occurred along the Jinsha River in China.

Eight different articles authored by lead scientists in physical modeling of landslides from seven countries in four different continents, such as from New Zealand, Indonesia, Malaysia, Japan, China, the USA, and Italy, cover the topics ranging from laboratory-based modeling of rock blocks to saturated as well as partially saturated soils, engineered to natural as well as tailings and submarine slopes, flume based to full scale as well centrifuge modeling, and caused by construction practices to wildfire as well as rainfall and earthquakes. Likewise, 17 different articles authors by global leaders on numerical modeling of landslides and debris flows, specifically from Taiwan, the UK, Belgium, Spain, Austria, Japan, Italy, Vietnam, and Serbia, cover various aspects of numerical modeling ranging from 1D to 3D, rock slope to soil slope, locally developed to commercially available software as well as GIS and remote sensing techniques, simple rendering to virtual reality techniques, rockfall to debris flows as well as dam break, natural to submarine slopes, finite element to discrete element as well as constitutive modeling, and saturated to unsaturated slopes. Moreover, nine articles authored by global scientific research leads from Italy, Sri Lanka, China, Indonesia, Japan, and the USA, on various aspects of soil and rock testing techniques as well as application and analysis methods, cover testing methods ranging from direct shear to ring shear as well as cyclic or monotonic simple shear tests, simple to customized tests, and laboratory to field tests. On the other hand, four papers authored by scientists from Turkey, Japan, and the UK on recent advancements in the methods of slope stability and deformation analyses cover topics ranging from 2D to 3D analyses methods, analysis techniques for movement mechanism to countermeasure design, soil to rock slopes, limit equilibrium to finite element as well as deformation analyses, and effects on shallow landslides to tsunami generating coastal slopes. Likewise, eight articles authored by global experts on landslide disaster risk assessment from Canada, India, Italy, Indonesia, Slovenia, New Zealand, Hong Kong, and Japan, cover various aspects of disaster risk assessment techniques ranging from saturated to unsaturated slopes, soil to rock slopes, and various causative factors spanning from wildfires to rainfall as well as earthquakes.

All papers published in this volume went through rigorous peer review process and were accepted with at least one affirmative review decision. The author would like to acknowledge the tireless work of the associate editors of this volume, Drs. Beena Ajmera, Sabatino Cuomo, Katsuo Sasahara, and Ryosuke Uzuoka for effectively handling the review process, specifically assigning the manuscripts to appropriate reviewers, and making decisions based on the reviewers' suggestion and their own judgement. Moreover, the author thanks over 50 reviewers who dedicated their time and effort to go over the manuscripts, review them, and provide constructive suggestions to improve the quality of the manuscripts.

Fullerton, CA, USA Binod Tiwari

Contents

Introduction—Testing, Modeling and Risk Assessment

Binod Tiwari, Beena Ajmera, Sabatino Cuomo, Katsuo Sasahara, and Ryosuke Uzuoka

Abstract

There has been a significant progress in landslide mitigation strategies in recent years. Recent advancement in physical or experimental and numerical modelling, testing methods to evaluate soil properties, and computing capabilities for slope and deformation analyses as well as landslide risk assessment lead the global scientists to prepare in advance for landslide hazard mitigation. The papers collected in this volume, authored by global leaders in scientific research pertinent to landslide hazard mitigation, provide testament of the progress we made recently on landslide hazard mitigation, specifically on recent development in testing, modelling and risk assessment methods.

Keywords

In-situ testing • Laboratory testing • Experimental modeling • Numerical modeling • Slope stability • Deformation analysis • Risk assessment

Background

While evaluating mass movement such as landslides and debris flows, properties of materials involved in the process play an important role. The material testing methods, instrumental as well as computational sensitivities, and accuracy levels have progressively been improved with the development of newer technology. Moreover, with the development of better technology every year, mass movement modeling techniques, both numerical and experimental, have significantly been improved in the past decade. Such modeling capabilities help researchers significantly to understand the mass movement behavior and perform sensitivity analyses at significantly lower cost compared to full scale models. One area that has significantly improved with the development of robust technology and efficient modeling techniques is landslide or debris flow risk assessment. Recent advancement in testing, modeling and risk assessment have been discussed routinely in various conferences and forums in the past, including the World landslide Forum 4 (Mikos et al. 2017a, b). Volume 4 of this book series (Tiwari et al. 2020) incorporates papers by leading scientists in the world who are making tireless efforts in research pertinent to the recent development and advancement in testing, modeling, and risk assessment for the mitigation of hazards caused by landslides, debris flows and other mass movements. This volume includes five keynote lectures and 45 peer reviewed papers in five different research areas pertinent to the theme of this volume. The entire volume is divided into six parts—(I) Keynote Lectures, (II) Recent Development in Physical Modeling of Landslides,

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(III) Recent Development in Numerical Modeling of Landslides, (IV) Recent Development in soil and rock testing techniques, application and analysis methods, (V) Recent advancements in the methods of slope stability and deformation analyses, and (VI) Recent Development in Disaster Risk Assessment. Presented in the subsequent sections are the brief descriptions of the papers covered in each part. All of these papers were peer reviewed and accepted with at least one affirmative review decision. The editors of this volume express their appreciation to the reviewers who have provided their valuable time to review the manuscript submitted in this volume.

Part I—Keynote Lectures

Tiwari and Ajmera (2020) has compiled state of the practice knowledge regarding shearing behavior and resistance of soil, specifically fully softened and residual shear strength, and recommended the procedure for utilizing residual and fully softened shear strengths for slope stability analysis in practice. In this key-note paper, the authors outlined the details regarding currently available testing methods and their benefits as well as limitations, regression equations to estimate such strengths with easily measurable index properties, and the influence of pore water chemistry as well as mineralogical compositions on these shear strengths. The authors also outlined various interpretation techniques to obtain shear strength parameters from laboratory test results and their influence in slope stability analysis results.

Stark and Xu (2020) describes the 2014 Oso Landslide in Washington focusing on the use of three computer programs to estimate the runout characteristics with the intent of comparing the results obtained with the field observations. The paper describes the two-phase failure of the landslide in which significant strength losses occur resulting in 1.4 km of movement and destroying a residential community. The material is described to undergo brittle failure during the second phase. Stark and Xu (2020) also describe the previous landslide history in the region. From their comparison of the runout results obtained from DAN3D, FLO-2D and Anura3D models, the authors find the runout zone is under-predicted by the FLO-2D model. The results from DAN3D and Anura3D were both found to be in good agreement with the field observations.

Pradel (2020) presents recent advancements geomechanical modelling, specifically in slope and deformation analysis, and provided some guidelines to use the results of such modelling in landslide stabilization practice. Two applications are considered in the key-note paper, which suit well for slope stability modelling. In the analysis of slope repairs and landslide stabilizations that combine multiple structural elements (e.g., several rows of piles with tiebacks), numerical modelling can enhance understanding. The seismic performance of slopes also greatly benefits from modelling, especially in the cases where dynamic amplification and permanent seismic displacements are a major concern.

Ajmera and Tiwari (2020) provided an extensive review on slope stability and deformation analysis methods available in practice. Such analyses range from easily developable excel spreadsheets to specific software programs as well as GIS software. This key-note paper details with the methods commonly used in practice for slope stability analysis both for natural as well as engineered slopes and outlines the importance of back analysis method to analyze stability of landslides. In this paper, the authors have included case studies available in the literature to illustrate some of the slope stability and deformation analysis methods.

The study by Zhang et al. (2020) presents a protocol for managing the risk of landslide hazard chains. This protocol is stated to quantify the amplification and overlapping effects of multiple hazards. This protocol is applied to landslide hazard chains for two large landslides that occurred along the Jinsha River. For these landslides, the measures implemented to reduce short and long-term risks and consequences are also described in the paper. The paper also presents an extensive list of future research avenues associated with landslide hazard chain risk management.

Part II—Recent Development in Physical Modeling of Landslides

Chen and Orense (2020) investigated the use of a magnetic tracking system applied at the laboratory-scale to measure the behaviour of the blocks as they propagate downslope. The system consists of permanent magnets as trackers and magnetometers as receivers. For various combinations of pile height, block volume and surface inclination, the displacements and orientations of the permanent magnet, representing one of the blocks undergoing movement, are monitored from which kinematic quantities are captured to highlight the behaviour of the blocks as they flow down the chute. The results obtained coincide very well with image analysis from video camera.

Yanto and Apriyono (2020) presents a new physically-based method for translational landslides to calculate the factor of safety. The proposed method was used to calculate the factor of safety for unsaturated and saturated materials. It is stated that unlike the previous methods, the method proposed in this study estimates the depth of the sliding surface as a function of the bearing capacity. Yanto and Apriyono (2020) compared the results from their method against field observations of landslides in the Sirampog and Kandang Serang subdistrict in Western Central Java. It was stated that there was good agreement.

Azmi et al. (2020) carried out an integrated analysis of rainfall-induced landslides through a laboratory test, as well as laboratory and numerical analyses. A set of laboratory-scale soil slopes was subjected to instability through different modes of rainfall intensities and slope inclination to clarify the process of failure initiation. A numerical analysis was also performed to confirm the effect of these factors on landslide occurrence. The results of the experiment and analyses concluded that the unsaturated slope stability analysis, setting the initial conditions and boundary condition, is important in dealing with the issues presented in their experiments.

Centrifuge model slope experiments with the increase of groundwater level were implemented by Hiraoka et al. (2020) to develop warning and evacuation alerts for workers in construction sites for slope excavation. Three cases of model slope with different slope angles were set up for the experiment. The results showed that the model slopes collapsed with groundwater while they did not collapse without groundwater under same slope angle. Shear deformation was measured by strain meters installed at the surface layers of the slopes. The deformation showed accelerative increase prior to the failure. Standard deviation of the increase of the deformation could be the criteria for alert. The slope might collapse soon when the increase of the deformation velocity exceeded the criteria based on the standard deviation.

To study the failure of tailing dam slopes, Hu et al. (2020) conducted a series of flume tests. The model slopes were constructed using iron waste deposits from the An-Nigh tailing pond in China and prepared to various relative densities. Hu et al. (2020) found that the failure mechanism varied based on the relative density with sudden collapses occurring when the relative density was less than 35% and progressive failures occurring when the relative density was greater. Specifically, sudden failure resulted when the saturation of caused densification of the soil mass resulting in the formation of crack that increased the pore pressure at the toe of slope. The authors also noted that multiple sliding surfaces initiating at the toe of the slope extending further upslope were characteristic of the progressive failures observed in their tests.

Tiwari (2020) measured velocity of infiltration of rainwater in model slope with different vegetation cover density under artificial rainfall to examine the influence of vegetation on surface runoff or infiltration during rainfall. Definition of vegetation cover, that the author considered, was ratio of area covered with leaves of a plant to that of slope surface area. Velocity of vertical infiltration of rainwater was larger until a certain value of vegetation cover density and it was almost constant above that threshold value. The result showed that the vegetation encouraged rainwater infiltration into the slope. Factor of safety of the slope was lower in the slope with vegetation cover of more density according to the slope stability analysis conducted by modelling the effect of a degree of saturation and vegetation cover density on shear strength of the soil in the slope.

Carey et al. (2020) studied potential failure mechanisms of submarine landslides in the laboratory. Specifically, the study evaluates mechanisms for both shallow and deep submarine landslides considering both the impacts of earthquakes and elevated pore pressures, separately. The experimentation is performed in a modified dynamic back pressure shear box using soils collected from the Tuaheni Landslide Complex off the east coast of New Zealand. From the results obtained, Carey et al. (2020) observed several different failure patterns. These observations were used to describe two potential failure mechanisms that submarine landslides may be subjected to.

The effect of rainfall infiltration on the stability of layered slopes were studied using flume tests in Capparelli et al. (2020). The study presents the results from three tests modeling slopes with (a) one layer comprised entirely of volcanic ash, (b) two layers consisting of pumice and volcanic ash and (c) three layers consisting of pumice between two layers of volcanic ash. Based on the results obtained, the authors conclude that the stability of the slope depended on the pumice layers in the models. The behavior of the pumice was noted to be dependent on the initial humidity and the intensity and duration of the rainfall applied. Capparelli et al. (2020) found that the ash hampered the drainage of pore pressures generated during the rainfall events, which will result in a reduction in the soil suction and the associated shear strength. As a result, localized shallow slope failures were observed in the one and three layer models., but not in the two layer model.

Part III—Recent Development in Numerical Modeling of Landslides

Ruiz-Carulla et al. (2020) proposes a model to replicate the fragmentation of a rockfall event. This model is, then, implemented in RockGIS, which is a three-dimensional trajectory rockfall simulator. To verify the proposed model, the authors used UAV surveys and digital photogrammetry to determine the block size distribution of a fragmented rockfall in Mallorca, Spain. The results from RockGIS were verified with the field observations finding good agreement between the two. It is also found that some of the smaller fragments are deposited along the path taken by the rockfall, while larger fragments reach a protection gallery causing a multi-impact effect.

Havenith (2020) discusses the use of virtual reality to visualize landslides. To do so, three-dimensional surface and geological models for several landslides sites with the intent of using them to perform slope stability analyses were